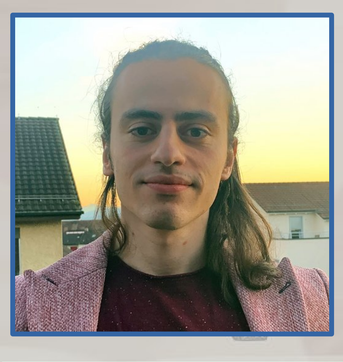
Coupling Secular Orbital and Atmospheric Evolution of Exoplanets



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CONTEXT

50% of detected exoplanets orbit around their star in less than a month, in extreme conditions. Yet, there is a surprising lack of Neptune-size worlds on very short orbits (Fig. 1, Lecavelier 07).

The origin of this striking **'Neptunian desert'** might be explained by the combined action of strong **atmospheric erosion and orbital migration** (Mazeh+16), as for the iconic GJ436b.

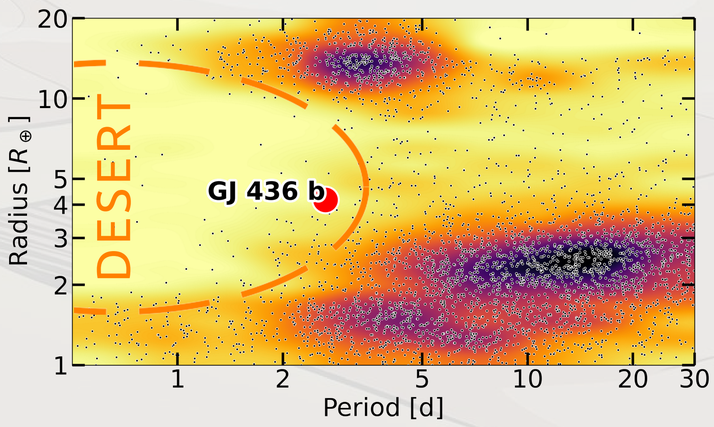
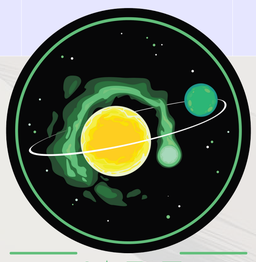


Fig. 1 – Demographics of the detected close-in planets

METHOD: THE JADE CODE

The JADE code (Attia+21) is an evolutionary model **combining** the most relevant **orbital and atmospheric processes** for close-in planets (Fig. 2), allowing the simulation of their whole secular history.

Dynamical features	Atmospheric features	Stellar features
• Kozai-Lidov resonance	• Atmospheric structure	• Evolving stellar fluxes
• Tidal effects	• Photo-evaporation	• Evolving spin vector
• General relativity	• Internal heating	• Contraction



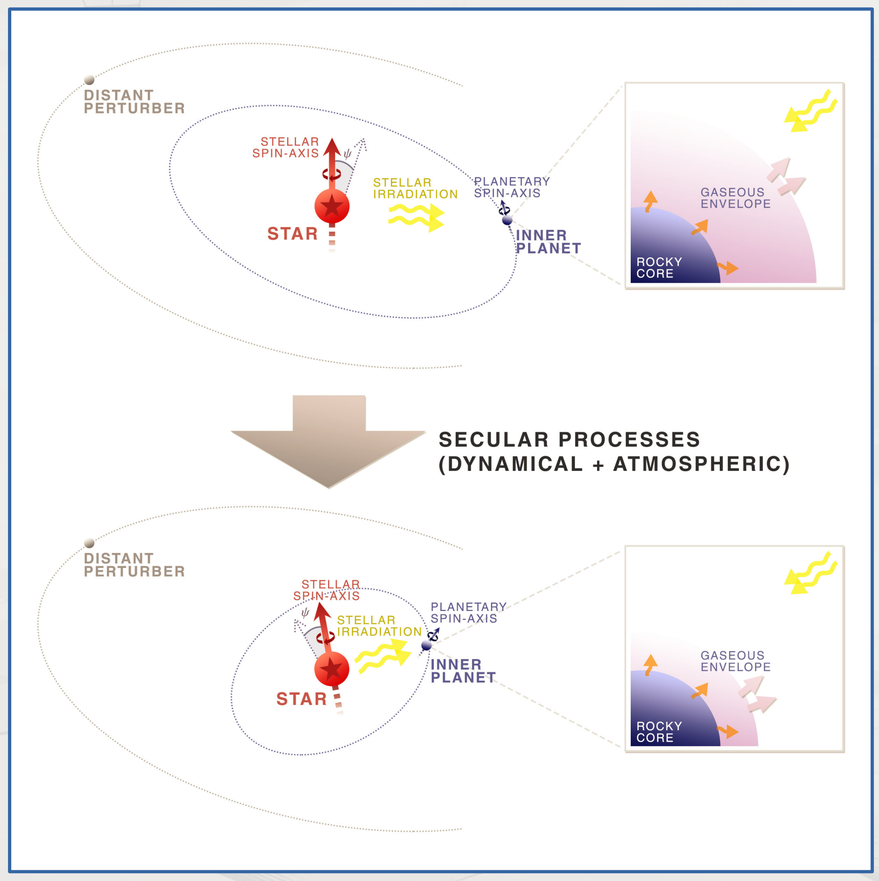


Fig. 2 – Illustration of how the JADE code works

APPLICATION: THE GJ436 SYSTEM

Previously, in the literature...

GJ436b (Butler+04) is inside the desert (Fig. 1). Its orbit is **eccentric** (0.14, Lanotte+14), which should have been damped by tides long ago.

A possible scenario invokes a **distant companion**, inducing a Kozai-Lidov resonance and a late migration (Bourrier+18, Fig. 3). These past works only investigated the lone **dynamical history** of the system, leaving the atmospheric aspect for us to explore...

The JADE code confirms past dynamical studies

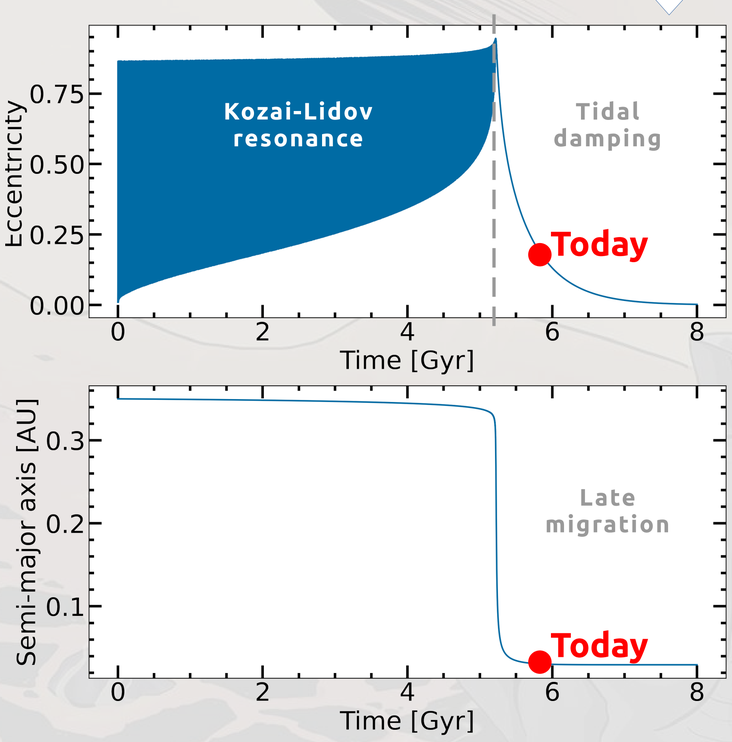


Fig. 3 – Eccentricity and semi-major axis evolution of GJ436 b under the influence of a distant companion, as simulated by the JADE code dynamical integrator

New mechanisms brought to light by the JADE code

We refine the Kozai-induced late migration scenario by also accurately **accounting for GJ436 b's atmosphere.**

Orbital feedback on the atmosphere

Kozai-Lidov → high-eccentricity cycles → close encounters with the star → heating/inflation cycles → **radius pulsations** (Fig. 4).

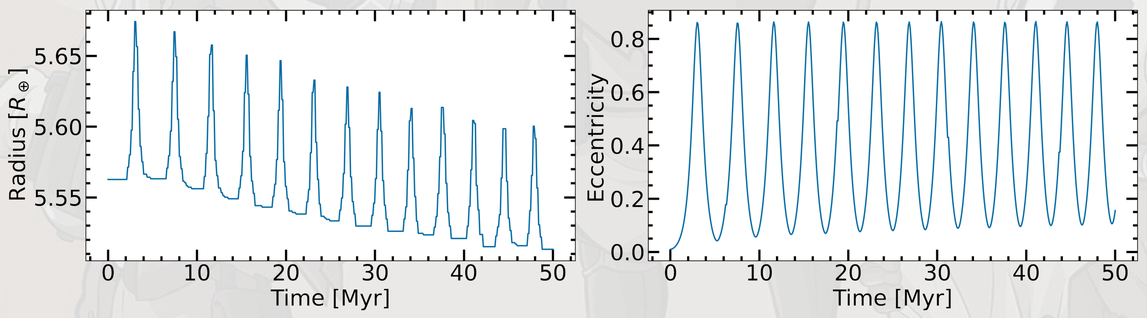


Fig. 4 – Radius pulsations of GJ436 b in tune with the Kozai-Lidov cycles, as simulated by the JADE code

Atmospheric feedback on the orbit

Radius pulsations (Fig. 4) → larger radius overall → stronger tidal effects → **earlier migration** and damping (Fig. 5).

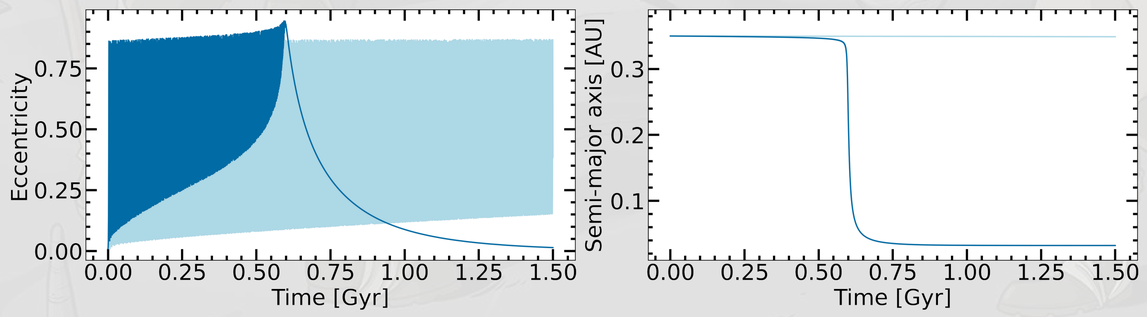


Fig. 5 – GJ436 b When the atmosphere of GJ436 b is taken into account (dark blue), the planet leaves the Kozai-Lidov resonance earlier than in the pure dynamical case (light blue)

CONCLUSION

- The JADE code allows you to self-consistently simulate the **secular evolution of close-in planets.**
- JADE simulations unveil a **strong coupling** between orbital and atmospheric processes on secular timescales. GJ436 is the first of many systems for which we rewind history back to their initial properties.
- The JADE code will be a valuable asset to disentangle the dynamical and atmospheric processes that **shape the desert.**

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